DRIFTWOOD

Michigan Technological University
Design Report 2019

Table of Contents

Executive Summary ii
Hull Design and Structural Analysis 1-2
Development and Testing 3-5
Construction 6-7
Project and Quality Management 8-9
Organization Chart 10
Project Schedule 11
Construction Drawing 12

List of Figures

Figure 1: Example X- and Y- coordinates of a Cross Section 2
Figure 2: Buoyant Force and Paddler Loads 2
Figure 3: Aggregate Proportioning by Volume 3
Figure 4: Microscope Image of K37 3
Figure 5: Overlap of SpiderLath 5
Figure 6: Verifying Concrete Depth 6
Figure 7: Progression of Canoe Construction 7
Figure 8: Creating the Imprints during Casting 7
Figure 9: Person-Hour Breakdown 8

List of Tables

Table 1: Properties of Driftwood ii
Table 2: Properties of the 2018-2019 Concrete Mixture ii
Table 3: Hull Design Comparison 1
Table 4: Properties of the Aggregates in the Final Concrete Mixture 4
Table 5: Comparison of Reinforcements 5
Table 6: Quality Management Program 9

List of Appendices

Appendix A: References A1
Appendix B: Mixture Proportions and Primary Mixture Calculation B1-B5
Appendix C: Example Structural Calculations C1-C3
Appendix D: Hull Thickness/Reinforcement and Percent Open Area Calculations D1-D3

Executive Summary

On Father's Day in 2018, the Michigan Technological (Michigan Tech) University campus and surrounding area of Houghton, MI experienced a 1000-year rainfall event (HCRD), causing considerable flooding and damage throughout the area. Not only was the town's infrastructure affected, but the banks along Lake Superior experienced extreme erosion, which disturbed the local beaches. The storm left debris along the shorelines and the Michigan Tech Concrete Canoe Team assisted the community in the clean-up. With this devastation in mind, the team decided to dedicate this year's boat, *Driftwood,* to Great Lakes' beaches to further support the recovering local community.

Michigan Tech is a public research university founded in 1885 and located in the Keweenaw Peninsula of Michigan's Upper Peninsula. The University sits on the Portage Canal just 11 miles from the largest of the Great Lakes, Lake Superior. The school has supported a concrete canoe team since 1991 and the team has found success at the North Central Student Conference. In 2018, the team placed second at the regional competition. They won the conference championship in both 2016 and 2017 and placed 8th and 11th at the national competition, respectively.

Table 1: Properties of Driftwood

Driftwood (2019)	
Weight	164 lbs.
Colors	White and Yellow
Maximum Length	20 feet
Maximum Width	27.1 inches
Maximum Depth	12.7 inches
Average Thickness	3/8th inch
Primary Reinforcement	GlasGrid® 8511 SpiderLath
Secondary Reinforcement	PVA-RFS400 PVA-RFS4000

This year, the Michigan Tech Concrete Canoe Team worked diligently to develop innovative techniques in nearly all aspects of the competition; the schedule, canoe construction, and aesthetic finishing underwent the greatest changes. The entire schedule was shifted with the intent of moving casting day four weeks earlier than previous years. A staggered construction plan was implemented to reduce the risk of cold joints, and the aesthetics committee incorporated pigment into the structural mix to decrease the use of the finishing mix.

To accomplish this year's overarching goal of constructing a lighter weight canoe, the Michigan Tech Concrete Canoe Team found inspiration in their community that worked collectively and tirelessly to rebuild the crucial infrastructure of their town. Much in the same way, the Michigan Tech Concrete Canoe Team utilized all of their resources and teamwork to provide this year's canoe with a superior finish.

Table 2: Properties of the 2018-2019 Concrete Mixture

Mixture	**Unit Weight (pcf)**		**Strength (psi)**				**Air Content (%)**
	Wet	Oven-Dry	Compressive		Tensile		
			14-Day	28-Day	14-Day	28-Day	
Structural	63.6	59.0	1,180	1,280	240	310	5.23
Pigmented Finishing	74.1	70.9	500	570	210	240	2.66
Composite Flexural Strength: 1,030 psi							

Hull Design

Driftwood was designed based on the performance of the 2018 hull design (Michigan Tech Concrete Canoe Team 2018), which was considerably altered from the previous year. Unfortunately, the 2018 canoe was not sufficiently tested due to the cancellation of race day at the regional competition. The team did test the canoe after the regional competition; however, was unable to test all five race scenarios due to the substantial ice coverage on the lake. With limited test data available, the hull design committee decided to only make minor changes to this year's hull design; the differences are shown in Table 3.

Table 3: Hull Design Comparison

	Backcountry (2018)	*Driftwood* *(2019)*
Length (ft.)	20.0	20.0
Length/Beam Ratio	8.513	8.715
Freeboard (ft.)	0.657	0.785
Wave Drag at 6 mph (N)	12.42	9.45

The overarching goals of the hull design committee were to improve travel velocity, straight-line tracking, and paddler efficiency. Utilizing PROLINES 98, a hull design modeling software, the width of all cross sections were reduced, and the widest point of the canoe was shifted towards the stern by 8.4 inches to decrease the wave drag by approximately 24 percent compared to last year. Wave drag is a function of velocity, therefore, a typical race speed of 6 mph was selected to compare wave drag values. With these alterations, the committee met the goals of improved travel velocity, paddler efficiency, and straight-line tracking. The result is an asymmetrical hull that features a long slender bow and stern, with flat and wide amidships. The turning ability was compromised as a result of the alterations, but the paddlers accepted this trade-off because the design already optimized turning ability.

A final step to finalize the hull design was constructing a lauan wood prototype, which allowed the paddlers to provide feedback to the hull design committee. Testing the prototype design verified that the hull design goals were met, and the design was then finalized. Furthermore, the prototype presented the paddlers with the opportunity to become comfortable with the final hull design prior to race day.

Structural Analysis

The goal of structural analysis was to provide the material development committees with the maximum stress values that the canoe will experience. Structural analysis began by deriving cross-sectional X- and Y-coordinates from the final hull design. Cross sections were taken in one-inch increments along the length of the canoe, and were transcribed into AutoCAD 2018. Figure 1 shows an example cross section. Using the coordinates for all 239 cross sections of *Driftwood,* mechanical properties were calculated using Microsoft Excel™. One of these properties was the area of each cross section, which was determined by connecting each coordinate pair to the adjacent coordinate pair with a rectangle representing the thickness of the canoe. This process was completed for every coordinate pair in each cross section. To account for overlaps and gaps of the rectangles, the spreadsheet was programed to only count the area once in the overlaps and to fill in the missing area in the gaps. Other properties that were calculated included the centroid, moment of inertia, and second moment of inertia. These properties were used alongside the five loading scenarios to meet the committee's goals of calculating the maximum compressive and tensile stresses experienced by the canoe during competition.

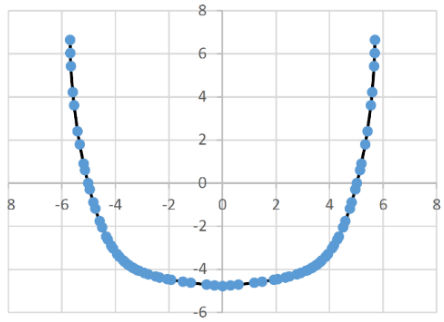


Figure 1: Example X- and Y-coordinates of a Cross Section

The five load cases analyzed were: transportation, display, men's race, women's race, and co-ed race. In all loading cases, the weight of the canoe was theoretically determined by utilizing the density of the structural mix and the area of each cross section. The transportation case considered the cradle used to transport the canoe and was modeled by an evenly distributed load on the top and bottom of the static canoe. The display scenario was modeled by four -point loads representing the canoe stands. The three racing scenarios were modeled using both sitting and kneeling paddlers. The paddlers were modeled as distributed loads, using the calculated distribution of their weight depending on if they were kneeling or sitting. A conservative 170 pounds for the women and 240 pounds for the men were applied and all possible variations of kneeling and sitting paddlers were modeled. Buoyancy forces were modeled for all race cases and loading combinations by initially determining how much of the boat displaced the water. Due to the asymmetrical hull design of the canoe, the committee had to first determine the angle the canoe actually sat in the water and how this affected the water displacement. To accomplish this, the committee ran an iterative Microsoft Excel™ program to determine the natural resting angle, starting with just one end in the water and ending with the opposite end solely in the water. The correct iteration was determined when the moment forces balanced to zero, and the canoe was in static equilibrium. At this point, the buoyancy force at each cross-sectional increment was determined for each paddler loading position, and these forces could then be applied to the racing scenarios. Figure 2 depicts the buoyancy forces due to paddler loads and the canoe's self-weight during a men's race. The unique shape of the upwards buoyant force is the result of the hull geometry canoe resting angle.

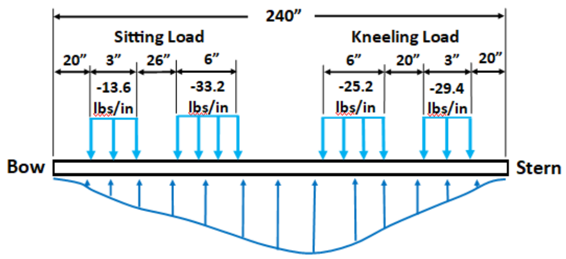


Figure 2: Buoyant Force and Paddler Loads

Once the forces were quantified, the rest of the two-dimensional analysis was completed to determine the critical stresses. *Driftwood* was found to experience the maximum stresses during the men's race when both paddlers were kneeling. The calculated maximum compressive stress the boat will experience is 235 psi along its chines, and the maximum tensile stress is 251 psi in its gunwale caps.

Next, the committee examined stresses attributed to punching shear. The load cases considered were a contact point from the kneeling or sitting position of both a male and female paddler. The maximum load case was determined to be a male paddler in a kneeling position with 63% of the paddler's 240-pound dynamic load being transferred through a single knee. Using a nominal thickness of 3/8th inch and a contact area of 6 inches by 3 inches, a maximum punching shear stress of 33.3 psi was calculated.

With these values determined, the committee met their structural analysis goal, and these maximum stress values were given to the research and development committee for their material testing and composite development.

Development and Testing

This year, the mixture committee established three goals to keep testing on schedule and continuously improve the mix: to utilize an enhanced or upgraded ASTM C330 compliant aggregate, explore the use of mineral fillers to increase strength, and to develop a mix that was less dense than water.

Predominant attributes from *Old Faithful* (Michigan Tech Concrete Canoe Team 2016) and *Powderstash* (Michigan Tech Concrete Canoe Team 2018) were used to provide a strong basis for this year's testing. Aggregate proportions from *Old Faithful* and proven K1 and K37 ratios from previous tests were combined and optimized to create the final, five-aggregate combination used in this year's structural concrete mix. As the rules concerning cementitious materials remained unchanged from last year, the binder blend from *Powderstash* was used as a baseline. The fiber blend in the mix was changed from the 50/50 blend to a 75/25 blend that favored the strengths of PVA RFS400 fibers. Individual concrete mixtures were tested at seven- and fourteen- day intervals for compressive strength (ASTM C39), split tensile strength (ASTM C496), and unit weight (ASTM C138). The broken cylinders were examined under a scanning electron microscope to understand how aggregates bonded with binders and to visualize why certain types of fibers provided higher strengths. Lessons learned from these examination sessions showed that larger K-series aggregates were pulverized during mixing and lost designed structural integrity. However, intact bubbles provided the mix with high strengths and a well-graded aggregate blend.

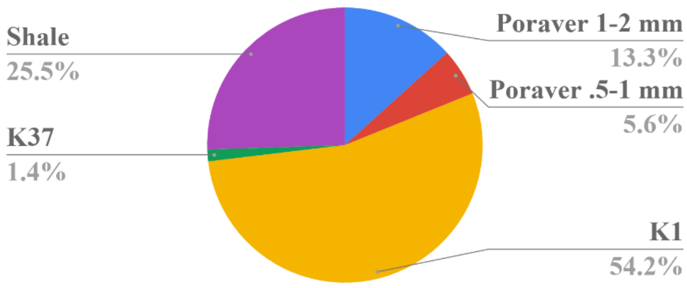


Figure 3: Aggregate Proportioning by Volume

Innovation is always a focus of our team; therefore, the mix design committee aspired to find new ways to reduce the overall weight of the canoe. One method was pigmenting the structural mix to reduce the amount of higher density finishing mix necessary to achieve the desired final product. Another approach was to use the new mineral filler rule to the team's advantage. By conducting a particle size distribution of the finer aggregates and using material technical data sheets to support the team's findings, the committee was able to classify a significant percentage of high strength, small gradation aggregates as mineral filler. This reduced the required volume of heavier ASTM C330 compliant aggregates. The committee decided to continue with its use of expanded shale based on its high strength values, the abundance of inventory from the previous year, and the team's familiarity with the material. A breakdown of the implemented aggregates and their properties are in Figure 3 and Table 4, respectively.

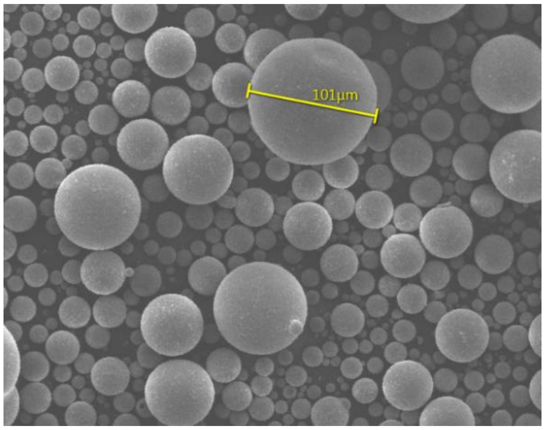


Figure 4: Microscope Image of K37

Due to the possible health hazards of sieving low density, ultra-fine aggregates and the potential for particles to become airborne, a particle size analysis was completed using a scanning electron microscope. This was used to further support the effective particle size found in material data sheets. Samples of K1 and K37 were determined to have 45% and 90% of particles passing a 75µm sieve, respectively. Figure 4 validates the material technical data sheets, since approximately 90% of the particles shown are less than 75µm.

To become more environmentally and economically sustainable, the mix committee reduced the number of mixes used both in testing and in applying the finishing mix to the canoe. Testing began by analyzing previous years' testing results and narrowing down the aspects of the mix that needed improvement. As a result, fewer mixes were tested, and less materials, time, and team funds were consumed while still producing a final product that exceeded all established goals. In addition, the concrete was mixed in a bucket instead of a drum to limit concrete waste and save mixing time. Casting day was improved, as a more workable mix made it possible for trowelers to produce a boat that was a consistent ⅜ inch thickness, reducing the number of unnecessary mixes to create the finished product.

Table 4: Properties of the Aggregates in the Final Concrete Mixture

Aggregate	Specific Gravity	Absorption (%)	Particle Size	% Retained in #200 Sieve
Poraver® 1-2 mm	0.39	20.0	1-2 mm	100%
Poraver® 0.5-1 mm	0.47	25.0	0.5-1 mm	100%
K1	0.125	0.0	≤ 120µm	55%
K37	0.37	0.0	≤ 85µm	10%
Shale	1.22	36.0	≤ 2.38 mm	100%

After these innovative and sustainable ideas were implemented, the mix committee reduced the final tier to three potential final mixes. Next, the mix design and reinforcement committees worked in unison to test the concrete mix and reinforcement schemes by creating composite beams designed to simulate a canoe wall, as described below. This sustainable development reduced the amount of beams tested and the two committees could both use the flexural strength values and visual analysis of the concrete and reinforcement bonding to finalize the mix design.

The goals of the reinforcement committee were to discover the right light-weight material and increase the workability of the reinforcement. These goals were based on this year's overall team goal to decrease the weight of the canoe and feedback from last year's trowelers. To accomplish these goals, three materials were tested: GlasGrid® 8511, SpiderLath, and FG-50. The reinforcement team liked the characteristics of GlasGrid® 8511, a fiberglass material used in last year's canoe, but wanted a lighter weight material. Research indicated that SpiderLath and FG-50 were each lightweight fiberglass materials with comparable strength and workability, making them viable options to consider.

To find the strength of the reinforcement, composite beams were tested using the three-point bend test in accordance to ASTM C1341. The reinforcement team sustainably used donated rolls of the three materials to test different combinations and orientations. Testing different orientations of the reinforcement was a new idea this year and was performed to determine if the different orientations would alter the bond between the mix and the reinforcement, ultimately increasing the total strength of the canoe.

When comparing the strengths of the differing orientations, the differences were negligible. Changing the orientation of the reinforcement created increased waste of material and cutting the reinforcement required additional time. Therefore, vertically-oriented reinforcement was used in the construction of *Driftwood*.

Comparing the properties, as seen in Table 5, and the workability of each material, FG-50 had the least desirable characteristics and was removed from consideration for the final scheme. SpiderLath provided greater strength than GlasGrid® 8511, but lacked strength when tested at the seams. The seam between reinforcement pieces is structurally considered as a weak point. To address this concern, the reinforcement committee ensured the seams from both layers of reinforcement were staggered to avoid parallel seams at any point. To replicate the staggered reinforcement pieces in a test a seam was only included in one layer of the reinforcement. The final reinforcement selection was SpiderLath on the inner layer with a 1 ½ inch overlap and GlasGrid® 8511 on the outer layer with no overlap, but rather interlocked. Figure 5 shows the 1 ½ inch overlap of the SpiderLath. This combination of reinforcement allowed for a decrease in weight and an increase in strength, flexibility, and workability. The remaining GlasGrid® 8511 from last year was utilized, adding to the team's environmental and economical sustainability. The SpiderLath was chosen for the inner layer due to its greater workability and flexibility. The flexibility of the SpiderLath allowed the team to innovatively fold the reinforcement into the gunwale caps and provide continuous strength to the canoe from the walls into the gunwale caps. Also, due to the stiffness of GlasGrid® 8511, the mesh tends to hold the rolled shape it is packaged in. To improve the workability and minimize the curvature of the mesh, the team unrolled and cut the reinforcing mesh five weeks before casting day and flattened it using weights.

Table 5: Comparison of Reinforcements

Reinforcement	Composite Flexural Strength (psi)	Weight $\left(\frac{lb}{ft^2}\right)$	Price $\left(\frac{\$}{ft}\right)$
GlasGrid® 8511	682	0.08	0.00
SpiderLath	1629	0.06	2.07
FG-50	653	0.08	1.00

The reinforcement committee attempted to increase the number of properties that were tested. Instead of choosing the reinforcement based solely on the strength, workability, price, and weight; the reinforcement committee searched to quantify the mix and reinforcement combination when under cyclic loading as well as the quality of bonding between the two. The charpy test (Gopalaratnam et. al. 1984) attempted to simulate the cyclic loads experienced by the canoe by using a "hammer", which is attached to a pivot point, to impact the point of interest. This test was not completed due to uncertainty that it would reflect the actual loads experienced by the canoe. A pullout test (Zastrau et. al. 2002) could quantify the bond between the mix and the reinforcement, but the committee decided against attempting the test since no applicable standard was found. The pullout test works by pulling on reinforcement that is protruding from a concrete cylinder. Although tests were unable to be finalized to quantify the additional reinforcement properties, the reinforcement committee hopes to further their research in years to come.

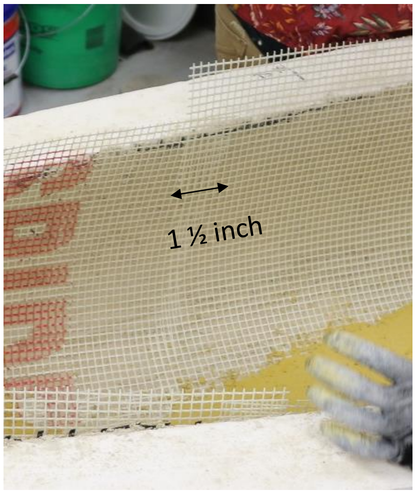


Figure 5: Overlap of SpiderLath

Construction

The primary goal of the construction committee was to achieve uniform layers of concrete with a focus on consistency on each individual layer. To accomplish this goal, the Quality Assurance & Quality Control (QA/QC) committee assisted the construction team through practice troweling sessions, organizing quality control during casting, and developing a new troweling technique.

Weekly troweling practice sessions helped to recruit, inform, and acclimate all members to the troweling committee. At these practices, the troweling committee worked with the reinforcement and structural mix committees to provide feedback on the workability of the reinforcement and structural mix designs. The troweling committee worked with the finalized mix design for the last month of training to familiarize themselves with the material prior to casting day. In an effort to be environmentally sustainable, all practice sessions utilized the previous year's mold sections. Through the training sessions, the troweling committee head decided on the appropriate number of trowelers. The committee head based the selection on the ability of the each troweler and their respective experience in troweling the various unique sections of the canoe. As a result, eight team members were chosen to trowel the concrete, while four team members were chosen to monitor the thickness of each layer. To ensure quality control throughout the entire process, the four team members used 3D-printed depth gauges set to 1/8th, 2/8th, and 3/8$^{th's}$ of an inch, representing each layer of the canoe (Figure 6).

Figure 6: Verifying Concrete Depth

One quality assurance measure used was to pre-batch materials prior to casting day. This shortened the mixing time during casting day and enhanced consistency throughout the batches. An additional quality assurance measure was a mock casting day, where team members constructed one portion of the canoe on a section of the previous year's mold. The mock casting day served as an extended troweling practice and exposed possible oversights that could occur during casting day.

The female mold was constructed upon finalizing the hull design. This high-density polystyrene foam mold was ordered and fabricated in six sections. The team has consistently procured the mold in this style because the CNC cut mold provides the most accurate representation of the hull design and eases mold construction. The six mold sections were combined using recycled pieces of plywood and screws, additionally, several layers of epoxy were applied to simplify the demolding process. With the mold constructed and trowelers prepared, the team was ready for casting day.

On the morning of casting day, the safety committee head outlined the necessary safety precautions before canoe construction could begin. The mix committee used a drill, a bucket, and the pre-measured materials to create the structural concrete mix. The team worked collectively to construct the canoe using an innovative technique to avoid cold joints. Traditionally, each layer of concrete was troweled in full prior to placing any reinforcement. This method left some sections to cure before reinforcement was laid. This year, the troweling committee introduced a new method, troweling all three layers in staggered sections from the bow to the stern. The trowelers placed the first 1/8th inch layer of concrete in the bow section then placed the first layer of reinforcement as soon as a wide enough section was troweled to fit a piece of reinforcement. Trowelers continued down the length of the canoe following this staggered method. As some trowelers worked on the first layer in the middle and stern sections, other trowelers worked on the second 1/8th inch layer of concrete in the bow. The inner layer of reinforcement was placed between the second and third layers of concrete. Concrete was continuously being placed on adjacent sections of the same layers and on the following layers. This method progressed through the casting process until the third 1/8th inch layer was completed. For an example of this progression see Figure 7. This new construction technique limited time between consecutive layers and as a result, allowed for the canoe to be successfully casted with no cold joints between layers.

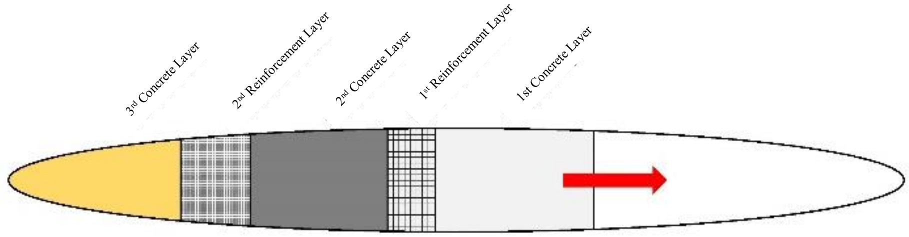


Figure 7: Progression of Canoe Construction

After placing the final layer, the aesthetics committee used cookie-cutters to imprint footprints onto the interior of the canoe (Figure 8). Foam end caps were then inserted into the bow and stern before being aesthetically troweled with concrete. Next, the gunwale cap molds were attached to the canoe mold, and the first 3/8th inch layer of concrete was troweled. The SpiderLath reinforcement was folded into the gunwales, and the last 3/8th inch layer of concrete was troweled to mark the conclusion of casting day and the start of the curing process.

To control the curing environment, a temporary structure and electric humidifiers were placed in the curing room. This created a curing environment of 90% humidity and 70°F, which was done in order to follow ASTM C511 in general accordance. The humidifiers ensured the cement was fully hydrated to properly bond and ultimately increase the compressive strength of the mix. After two weeks of monitoring these conditions, the fourteen-day compressive strength of the concrete was great enough to start the demolding process. The entire team participated by holding the canoe while the foam pieces were separated from each other. Carefully, the mold sections were removed from the canoe's exterior, so the aesthetics committee could begin.

Figure 8: Creating the Imprints during Casting

The goals of the aesthetics committee were to sustainably decrease the amount of finishing mix and to improve the smoothness and consistency of the final product. To accomplish these goals, pigments were added to the structural mix. White pigment was added to the outer layer, no pigments were added to the middle layer, and yellow was added to the inside layer. These pigments were added according to the aesthetics plan of a dinghy on the outside and a beach on the inside. The team sanded the canoe, first with 80-grit sandpaper and gradually progressed to 320-grit sandpaper. The footprints were aesthetically enhanced with a dark color to create depth before being sanded. Concrete seashells were constructed and placed on the inside of the canoe as outlays. Lastly, two coats of sealer were applied to the canoe and then wet sanded with 1000-grit sandpaper.

Project and Quality Management

The Michigan Tech Concrete Canoe Team elected a new junior project manager at the end of the 2017-2018 school year. The two current project managers practiced social sustainability and knowledge transfer to prepare the new project manager to lead the team in the future years. At the end of the 2017-2018 school year, new committee heads were chosen for each committee. All candidates presented their ideas, interest, and knowledge of a committee, and a vote was completed to pick each committee head. Generally, first year members are encouraged to participate in all committees and wherever help is needed. Then at the end of their first year they are able to run for a committee head position. This structure allows members to understand the entire process of constructing a canoe, encourages leadership development, and allows for greater cohesion among committees.

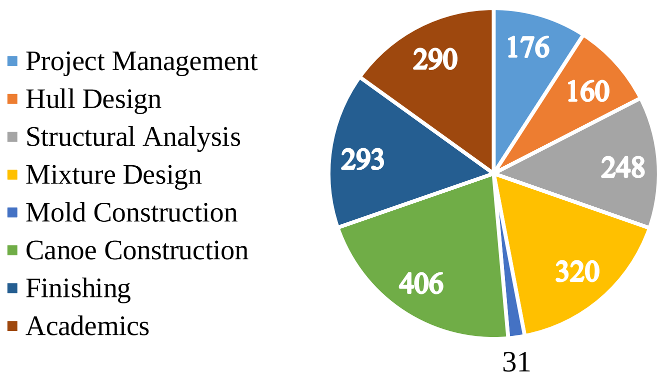


Figure 9: Person-Hour Breakdown

The main goal of the project managers was to implement a schedule that allowed the canoe to be casted in the fall semester. Therefore, the scheduling and enforcement of the schedule were crucial to the team's success. At the beginning of the year, the project managers worked with the committee heads to create a schedule that was feasible, setting deadlines for each committee to achieve the goal of a fall cast. The major milestones for the overall project were hull design completion, mixture design selection, primary reinforcement determination, casting, and the Project Overview and Technical Addendum (POTA) and Design Paper submissions. Activities were determined so that the critical path could be established. Critical path examples are prototype construction and structural mix development. If these critical path items were delayed, the entire project would be delayed. At weekly team meetings, the project managers would remind the team of important deadlines and each committee head would provide a summary of the work completed that week and the plan for the upcoming week. In addition to weekly team meetings, the project managers and committee heads met to discuss successes, failures, and schedule progress. At these additional meetings, the committee heads asked other committee members for help and any necessary material procurement was completed. Although all the committee heads completed their tasks by the deadlines, the team was unable to complete a fall cast due to delays with procuring the mold. This delay was overcome by the aesthetics committee adjusting their schedule to complete the project by the deadline. Future project schedules will designate mold procurement as a critical path item, in hopes of avoiding this problem in the future. Overall on this project, an estimated 1924 person-hours were spent. A breakdown of these person-hours is shown in Figure 9.

A project budget was developed based on last year's final budget, which was reviewed and updated for projected 2019 costs. To be economically sustainable, the team purchases many materials in bulk to alleviate repetitive yearly costs. Fundraising efforts were undertaken to obtain the desired funds for each committee. The fundraising committee distributed a newsletter to update donors, friends, and family of the team's previous yearly performance, future plans, and ways to contribute to the team. The team also receives support from various academic departments at Michigan Tech. In addition, each committee head maintains relationships with companies who have previously donated materials.

The Michigan Tech Concrete Canoe Team has access to a lab on campus to complete all necessary work, including material testing and canoe construction. All team members completed online training in general safety awareness, hazards, ladder safety, the university chemical hygiene plan, and electrical safety to obtain access to the lab. All members participated in on-site training with the lab advisor at Michigan Tech. The safety committee head works closely with the lab advisor to ensure the proper personal protection equipment is used for every situation. The committee head gives a safety focus of the week to reinforce the safety training. The team's safety procedure was put to the test when the canoe was removed from the basement of the lab. Utilizing a crane the team moved the canoe through the ceiling of the basement onto the ground floor. The lab advisor operated the crane while the team guided the canoe through the ceiling. Under the watchful eye of the lab advisor and the safety committee head, the team successfully completed this obstacle with no incidents.

Table 6: Quality Management Program

Schedule Control	Communications
	Material Procurement
	Budget
Compliance Control	Technical Review
	Documentation
Knowledge Control	Training
	Recruitment
	Things Learned

The QA/QC plan set forth by the Michigan Tech Concrete Canoe Team was created in 2017 and modified in 2018. The current plan has three broad categories that are then further divided, shown in Table 6. In schedule control, the project managers and committee heads communicate about deadlines to ensure no delays. To avoid issues with material procurement, a list of the necessary materials was provided to the project managers by each committee at the beginning of the year. The treasurer played an important role with material procurement to monitor each committee's budget and ensure individual reimbursement.

Compliance control was monitored by the compliance committee, each committee head, and the project managers. The compliance committee was in charge of ensuring each committee was in compliance with the Rules and Regulations (ASCE 2019) provided by the competition and notifying the appropriate committee head about all RFIs. To aid in documentation and ease of technical review, all team members have access to a common database. Lastly, the team prepares a mock display day where the project managers ensure all the Rules and Regulations (ASCE 2019) are followed.

Knowledge control is practiced by a 'things learned' document filled out every year by each committee head to describe successes, failures, and to help future committee heads. The team recruits heavily throughout the year to ensure a wide range of majors, experience, and interests are represented by the team. Each committee head trains all members who assist with their committee. Knowledge control is crucial to the efficiency and advancement of the Michigan Tech Concrete Canoe Team, as well as for encouraging social sustainability.

Sustainability and innovation were the common themes among all committees and in the efforts of the local community to clean up the beaches after this past summer's devastating floods. Therefore, the team used sustainable and innovative ideas to complete the project and help the recovering community.

Project Managers

Project Managers are responsible for keeping the team organized, on track, and working toward their goals.

Liz Adams, Sr.*

Cole Schilling, Sr.

Mary Kinney, Jr.*

Research & Development

Derrick Sullivan, Jr.
Assisted By: Allison Dagesse, Sr., Charlie Hill, Sr., Sophie Steinbrueck, Sr., Lauren Bowling, So.

Responsible for the development and testing of mix designs, as well as reinforcement schemes and canoe aesthetics.

Academics

Mary Kinney, Jr.
Assisted By: Leah DeSimpelare, Sr., Jakob Janquart, Sr., Ryan Olsen, Sr., Conner Reed, Jr.
Presenters: Leah DeSimpelare, Sr., Conner Reed, Jr., Derrick Sullivan, Jr., Lauren Cole, So.

Responsible for structural analysis, hull design, design paper, and compliance.

Construction

Connor Green, Sr.
Assisted By: Jacob Boecker, Sr., Lauren Bowling, So., Nick Hoffbeck, So.

Responsible for casting day and all preparations, as well as stands, cross-section, and display construction.

Paddling

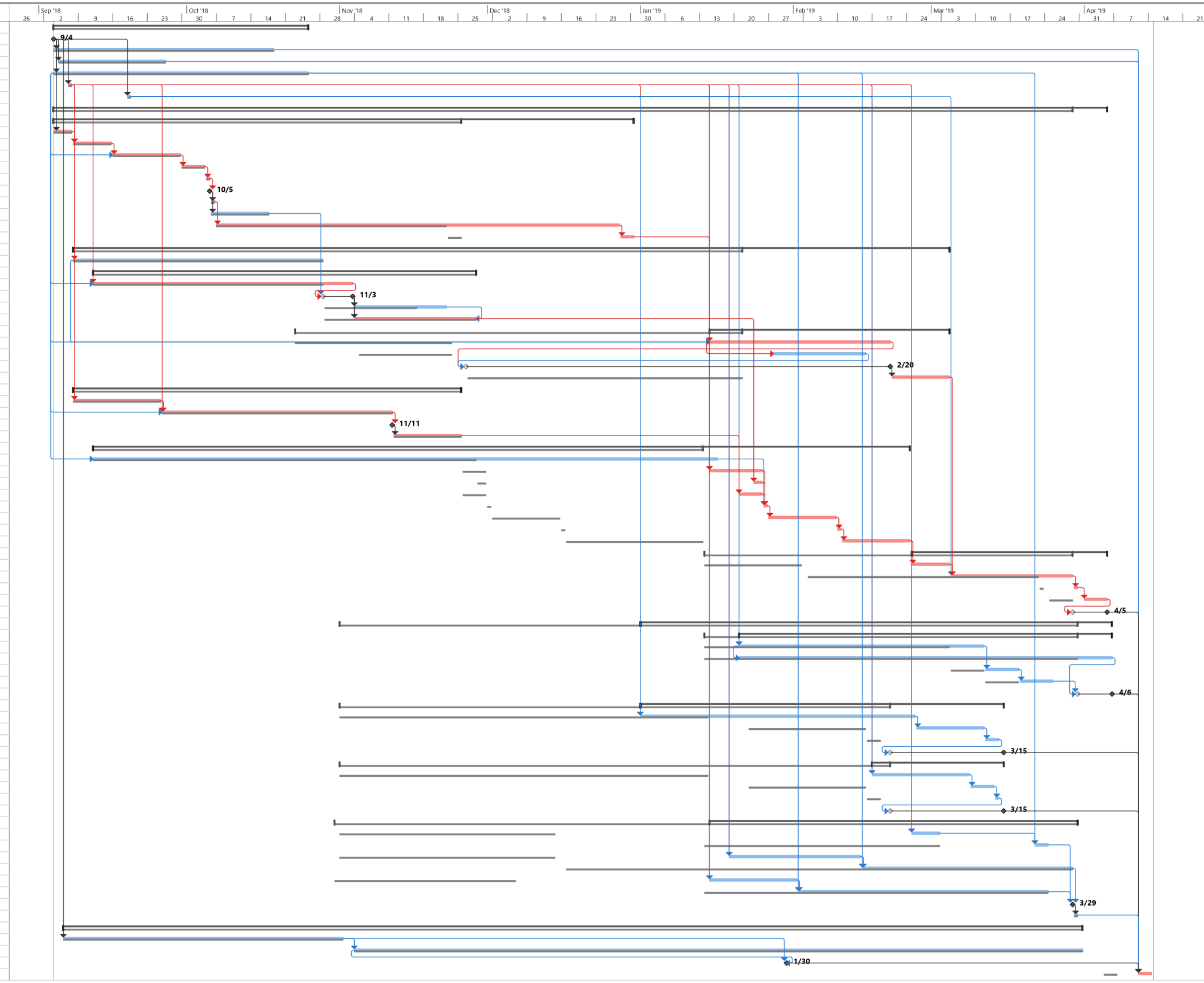
Liz Adams, Sr. & Danny Jones, Sr.
Paddlers: Liz Adams, Sr., Leah DeSimpelare, Sr., Danny Jones, Sr., Karl Heindlmeyer, Jr., Mary Kinney, Jr., Derrick Sullivan, Jr., Lauren Bowling, So., Lauren Cole, So., Nick Hoffbeck, So.

Responsible for teaching, training, and preparing paddlers for competition.

* Denotes Team Captains

Project Schedule

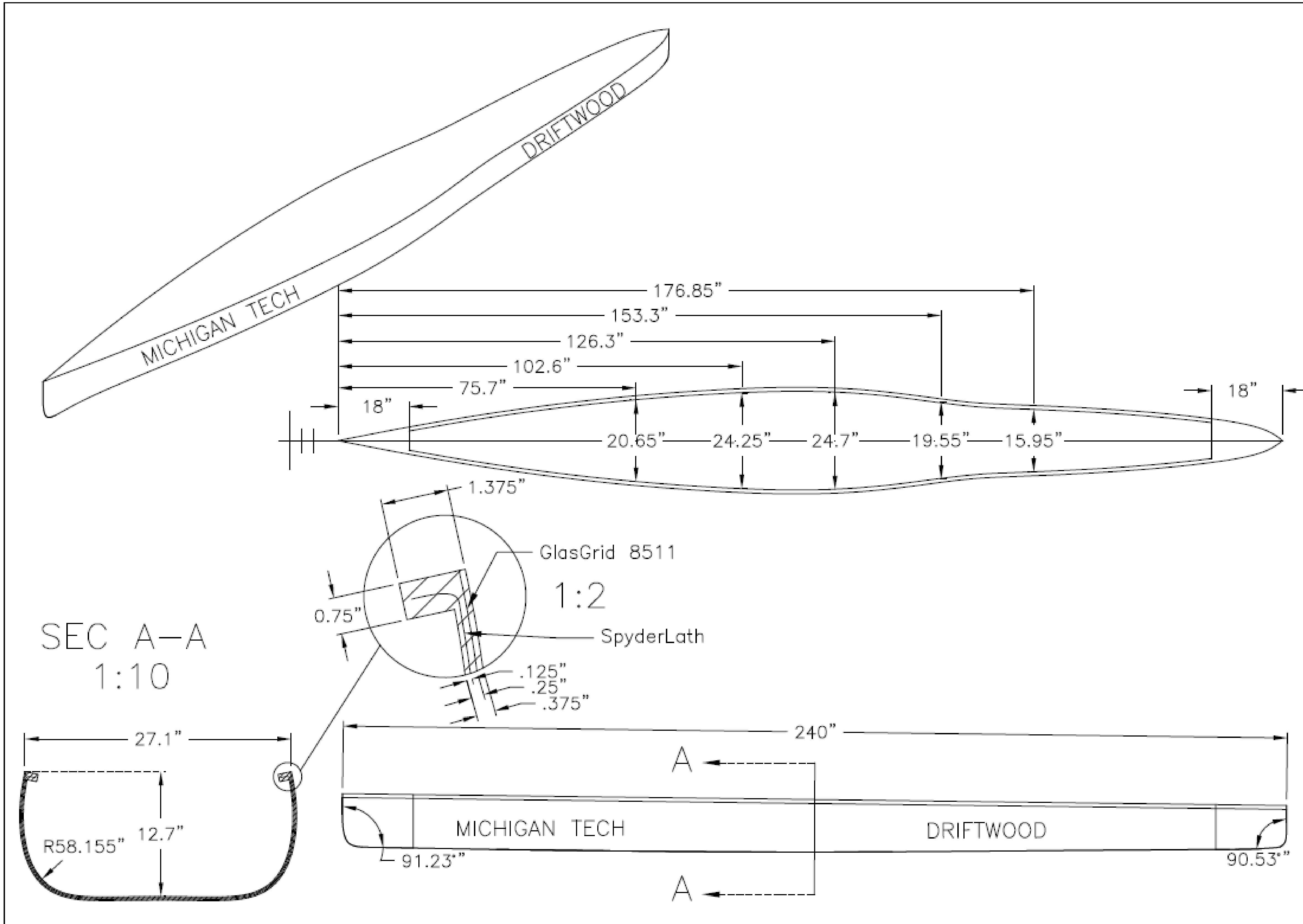
ID		Task Mode	Task Name	Duration	Start	Finish	Baseline Start	Baseline Finish
1			**Project Management**	**52 days**	**Tue 9/4/18**	**Thu 10/25/18**	**Tue 9/4/18**	**Thu 10/25/18**
2			Start of Academic Year	0 days	Tue 9/4/18	Tue 9/4/18	Tue 9/4/18	Tue 9/4/18
3			Fundraising - Fall Newsletter	45 days	Tue 9/4/18	Thu 10/18/18	Tue 9/4/18	Thu 10/18/18
4			Recruitment	22 days	Wed 9/5/18	Wed 9/26/18	Wed 9/5/18	Wed 9/26/18
5			Lab Safety Training	52 days	Tue 9/4/18	Thu 10/25/18	Tue 9/4/18	Thu 10/25/18
6			Rules Released & Reviewed	1 day	Fri 9/7/18	Fri 9/7/18	Fri 9/7/18	Fri 9/7/18
7			Theme Decision	1 day	Wed 9/19/18	Wed 9/19/18	Wed 9/19/18	Wed 9/19/18
8			**Canoe Development**	**214 days**	**Tue 9/4/18**	**Fri 4/5/19**	**Tue 9/4/18**	**Fri 3/29/19**
9			**Hull Design**	**118 days**	**Tue 9/4/18**	**Sun 12/30/18**	**Tue 9/4/18**	**Sun 11/25/18**
10			Hull Design Research	4 days	Tue 9/4/18	Fri 9/7/18	Tue 9/4/18	Fri 9/7/18
11			Draft Initial Hull Design	8 days	Sat 9/8/18	Sat 9/15/18	Sat 9/8/18	Sat 9/15/18
12			Prototype Construction	14 days	Sun 9/16/18	Sat 9/29/18	Sun 9/16/18	Sat 9/29/18
13			Prototype Testing	5 days	Sun 9/30/18	Thu 10/4/18	Sun 9/30/18	Thu 10/4/18
14			Rework of Hull Design	1 day	Fri 10/5/18	Fri 10/5/18	Fri 10/5/18	Fri 10/5/18
15			Final Hull Design Selection	0 days	Fri 10/5/18	Fri 10/5/18	Fri 10/5/18	Fri 10/5/18
16			Release Hull Dimensions	1 day	Sat 10/6/18	Sat 10/6/18	Sat 10/6/18	Sat 10/6/18
17			Structural Analysis	12 days	Sat 10/6/18	Wed 10/17/18	Sat 10/6/18	Wed 10/17/18
18			Foam Sized and CNC Milled	82 days	Sun 10/7/18	Thu 12/27/18	Sun 10/7/18	Thu 11/22/18
19			Mold Pick-up and Delivery	3 days	Fri 12/28/18	Sun 12/30/18	Fri 11/23/18	Sun 11/25/18
20			**Concrete Mix Design**	**178 days**	**Sat 9/8/18**	**Mon 3/4/19**	**Sat 9/8/18**	**Mon 1/21/19**
21			Material Procurement for Testing	51 days	Sat 9/8/18	Sun 10/28/18	Sat 9/8/18	Sun 10/28/18
22			**Structural Mix**	**78 days**	**Wed 9/12/18**	**Wed 11/28/18**	**Wed 9/12/18**	**Wed 11/28/18**
23			Binder, Aggregate, and Fiber Testing	53 days	Wed 9/12/18	Sat 11/3/18	Wed 9/12/18	Sun 10/28/18
24			Final Structural Mix Selection	0 days	Sat 11/3/18	Sat 11/3/18	Sun 10/28/18	Sun 10/28/18
25			Final Structural Mix Testing	19 days	Sun 11/4/18	Thu 11/22/18	Mon 10/29/18	Fri 11/16/18
26			Final Structural Mix Material Procurement	25 days	Sun 11/4/18	Wed 11/28/18	Mon 10/29/18	Wed 11/28/18
27			**Finishing Mix**	**49 days**	**Tue 1/15/19**	**Mon 3/4/19**	**Tue 10/23/18**	**Mon 1/21/19**
28			Finishing Mix Design & Testing	37 days	Tue 1/15/19	Wed 2/20/19	Tue 10/23/18	Fri 11/23/18
29			Application Technique Testing	19 days	Mon 1/28/19	Fri 2/15/19	Mon 11/5/18	Fri 11/23/18
30			Final Finishing Mix Selection	0 days	Wed 2/20/19	Wed 2/20/19	Mon 11/26/18	Mon 11/26/18
31			Final Finishing Mix Material Procurement	12 days	Thu 2/21/19	Mon 3/4/19	Tue 11/27/18	Mon 1/21/19
32			**Reinforcement**	**79 days**	**Sat 9/8/18**	**Sun 11/25/18**	**Sat 9/8/18**	**Sun 11/25/18**
33			Material Procurement for Testing	18 days	Sat 9/8/18	Tue 9/25/18	Sat 9/8/18	Tue 9/25/18
34			Reinforcement Testing	47 days	Wed 9/26/18	Sun 11/11/18	Wed 9/26/18	Sun 11/11/18
35			Final Reinforcement Selection	0 days	Sun 11/11/18	Sun 11/11/18	Sun 11/11/18	Sun 11/11/18
36			Final Reinforcement Material Procurement	14 days	Mon 11/12/18	Sun 11/25/18	Mon 11/12/18	Sun 11/25/18
37			**Canoe Construction**	**166 days**	**Wed 9/12/18**	**Sun 2/24/19**	**Wed 9/12/18**	**Sun 1/13/19**
38			Casting Practices	127 days	Wed 9/12/18	Wed 1/16/19	Wed 9/12/18	Wed 11/28/18
39			Mold Assembly	11 days	Tue 1/15/19	Fri 1/25/19	Mon 11/26/18	Fri 11/30/18
40			Pre-Batch Final Structural Mix	2 days	Thu 1/24/19	Fri 1/25/19	Thu 11/29/18	Fri 11/30/18
41			Pre-Cut Reinforcement	5 days	Mon 1/21/19	Fri 1/25/19	Mon 11/26/18	Fri 11/30/18
42			Concrete Placement	1 day	Sat 1/26/19	Sat 1/26/19	Sat 12/1/18	Sat 12/1/18
43			Initial Cure with Mold	14 days	Sun 1/27/19	Sat 2/9/19	Sun 12/2/18	Sat 12/15/18
44			Mold Removal	1 day	Sun 2/10/19	Sun 2/10/19	Sun 12/16/18	Sun 12/16/18
45			Final Curing	14 days	Mon 2/11/19	Sun 2/24/19	Mon 12/17/18	Sun 1/13/19
46			**Finishing & Aesthetics**	**40 days**	**Mon 2/25/19**	**Fri 4/5/19**	**Mon 1/14/19**	**Fri 3/29/19**
47			Sanding	8 days	Mon 2/25/19	Mon 3/4/19	Mon 1/14/19	Sat 2/2/19
48			Interior & Exterior Design	25 days	Tue 3/5/19	Fri 3/29/19	Mon 2/4/19	Fri 3/22/19
49			Finish Aesthetic Design	1 day	Sat 3/30/19	Sat 3/30/19	Sat 3/23/19	Sat 3/23/19
50			Sealing	5 days	Mon 4/1/19	Fri 4/5/19	Mon 3/25/19	Fri 3/29/19
51			Finishing Complete	0 days	Fri 4/5/19	Fri 4/5/19	Fri 3/29/19	Fri 3/29/19
52			**Communications**	**96 days**	**Tue 1/1/19**	**Sat 4/6/19**	**Thu 11/1/18**	**Sat 3/30/19**
53			**Technical Presentation**	**76 days**	**Mon 1/21/19**	**Sat 4/6/19**	**Mon 1/14/19**	**Sat 3/30/19**
54			Create Presentation	50 days	Mon 1/21/19	Mon 3/11/19	Mon 1/14/19	Mon 3/4/19
55			Presentation Practice	76 days	Mon 1/21/19	Sat 4/6/19	Mon 1/14/19	Sat 3/30/19
56			Professional Reviews	7 days	Tue 3/12/19	Mon 3/18/19	Tue 3/5/19	Mon 3/11/19
57			Final Revision	7 days	Tue 3/19/19	Mon 3/25/19	Tue 3/12/19	Mon 3/18/19
58			Presentation Complete	0 days	Sat 4/6/19	Sat 4/6/19	Sat 3/30/19	Sat 3/30/19
59			**Design Paper**	**74 days**	**Tue 1/1/19**	**Fri 3/15/19**	**Thu 11/1/18**	**Wed 2/20/19**
60			Paper Outline & Draft	56 days	Tue 1/1/19	Mon 2/25/19	Thu 11/1/18	Mon 1/14/19
61			Professional Reviews	14 days	Tue 2/26/19	Mon 3/11/19	Wed 1/23/19	Fri 2/15/19
62			Final Revision	3 days	Tue 3/12/19	Thu 3/14/19	Sat 2/16/19	Mon 2/18/19
63			Design Paper Submission	0 days	Fri 3/15/19	Fri 3/15/19	Wed 2/20/19	Wed 2/20/19
64			**Project Overview and Technical Addendum**	**27 days**	**Sun 2/17/19**	**Fri 3/15/19**	**Thu 11/1/18**	**Wed 2/20/19**
65			POTA Outline & Draft	20 days	Sun 2/17/19	Fri 3/8/19	Thu 11/1/18	Mon 1/14/19
66			Professional Reviews	5 days	Sat 3/9/19	Wed 3/13/19	Wed 1/23/19	Fri 2/15/19
67			Final Revision	1 day	Thu 3/14/19	Thu 3/14/19	Sat 2/16/19	Mon 2/18/19
68			POTA Submission	0 days	Fri 3/15/19	Fri 3/15/19	Wed 2/20/19	Wed 2/20/19
69			**Final Product Display**	**75 days**	**Tue 1/15/19**	**Sat 3/30/19**	**Wed 10/31/18**	**Sat 3/30/19**
70			Cross Section Design	6 days	Mon 2/25/19	Sat 3/2/19	Thu 11/1/18	Fri 12/14/18
71			Cross Section Construction	3 days	Fri 3/22/19	Sun 3/24/19	Mon 1/14/19	Sat 3/2/19
72			Table Top Display Design	27 days	Sat 1/19/19	Thu 2/14/19	Thu 11/1/18	Fri 12/14/18
73			Table Top Display Construction	43 days	Fri 2/15/19	Fri 3/29/19	Mon 12/17/18	Fri 3/29/19
74			Display Stands Design	18 days	Tue 1/15/19	Fri 2/1/19	Wed 10/31/18	Thu 12/6/18
75			Display Stands Construction	51 days	Sat 2/2/19	Sun 3/24/19	Mon 1/14/19	Sun 3/24/19
76			Final Product Display Complete	0 days	Fri 3/29/19	Fri 3/29/19	Fri 3/29/19	Fri 3/29/19
77			Compliance Check	1 day	Sat 3/30/19	Sat 3/30/19	Sat 3/30/19	Sat 3/30/19
78			**Paddler Training**	**207 days**	**Thu 9/6/18**	**Sun 3/31/19**	**Thu 9/6/18**	**Sun 3/31/19**
79			Outdoor Paddling Practice	57 days	Thu 9/6/18	Thu 11/1/18	Thu 9/6/18	Thu 11/1/18
80			Indoor Paddling Practice	148 days	Sun 11/4/18	Sun 3/31/19	Sun 11/4/18	Sun 3/31/19
81			Selection of Competition Paddlers	0 days	Wed 1/30/19	Wed 1/30/19	Wed 1/30/19	Wed 1/30/19
82			**North Central Student Conference**	3 days	Fri 4/12/19	Sun 4/14/19	Fri 4/5/19	Sun 4/7/19



Michigan Technological University
Concrete Canoe
2018-2019 Preliminary Schedule

Baseline Milestone ◇ | Baseline Summary | Task | Milestone ◆ | Summary | Critical | Baseline

Page 1



Michigan Technological University

I.D.	DESCRIPTION	QTY.
1	Lehigh White Type 1 Portland Cement C–15	68.37 lb
2	Blast Furnace Slag	14.17 lb
3	Class C Fly Ash	25.89 lb
4	NYCON RF4000(30mm) PVA	.74 lb
5	NYCON RFS400(19mm) PVA	1.12 lb
6	GlasGrid 8511	63.94 ft^2
7	SpyderLath	63.94 ft^2
8	Digeronimo Haydite	23.07 lb
9	DOW Great Stuff Pro Spray Foam	1.5 ft^3
10	3M Glass Bubbles K1	10.25 lb
11	3M Glass Bubbles K37	3.31 lb
12	Poraver 1–2 mm	3.31 lb
13	Poraver 0.5–1 mm	1.65 lb
14	Poraver 0.25–0.5 mm	.30 lb
15	Poraver 0.1–0.3 mm	.84 lb
16	Distilled Water	62.11 lb
17	Direct Colors Concrete Pigments	1.83 lb
18	Armor WB25 Acrylic Sealer	1.50 gal
19	BASF Glenium 3030 NS	0.05 gal
20	Tylac 4190	0.11 gal
21	Silhouette Glossy Permanent Vinyl	3.00 ft^2

Construction Drawing

DRAWN BY: CONNER REED	CHECKED BY: JAKOB JANQUART
DATE: 3/2/2019	SHEET: 12
SCALE: 1:25 OR AS NOTED	

Appendix A – References

ASCE/NCCC. (2019). 2019 American Society of Civil Engineers National Concrete Canoe Competition Rules and Regulations. ASCE. <http://www.asce.org/rules-and-regulations/> (October 10, 2018).

ASTM International. (2013). “Standard Test Method for Flexural Properties of Continuous Fiber-Reinforced Advanced Ceramic Composites”. C1341-13. West Conshohocken, PA.

ASTM International. (2013). “Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes”. C511-13. West Conshohocken, PA.

ASTM International. (2014). “Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete”. C138/C138M-17a. West Conshohocken, PA.

ASTM International. (2015). “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens”. C39/C39M-15a. West Conshohocken, PA.

ASTM International. (2017). “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens”. C496/C496M-17. West Conshohocken, PA.

ASTM International. (2017). “Standard Specification for Lightweight Aggregates for Structural Concrete”. C330/C330M-17. West Conshohocken, PA.

AutoCAD 2018. Computer Software. Autodesk, Inc., San Rafael, CA.

Michigan Tech Concrete Canoe Team. (2016). Denali: Michigan Technological University Design Report. Houghton, Michigan.

Michigan Tech Concrete Canoe Team. (2018). Backcountry: Michigan Technological University Design Report. Houghton, Michigan.

Microsoft Excel. Computer Software. Microsoft, Redmond, WA.

HCRC. “Flood Presentation.” (n.d.). *Houghton County Road Commission,* http://www.houghtoncountyroad.org/docs/flood_presentation.pdf (Jan.12, 2019).

Gopalaratnam, V., and Shah, S. (1984). “Instrumented Impact Testing of Brittle Materials.” Engineering Mechanics in Civil Engineering: Proceedings of the Fifth Engineering Mechanics Division Specialty Conference, 1, 635–639.

PROLINES 98. Computer Software. Vacanti Yacht Design LLC, Anacortes, WA.

Zastrau, B., Richter, M., and Lepenies, I. (2002). “On the Analytical Solution of Pullout Phenomena in Textile Reinforced Concrete.” Journal of Engineering Materials and Technology, 125(1), 38–43.

Cover photo and Organization Chart shot in Bayfield, Wisconsin, courtesy of Sophie Steinbrueck.

Appendix B – Mixture Proportions and Primary Mixture Calculation

MIXTURE DESIGNATION: STRUCTURAL

Cementitious Materials				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Lehigh Type 1 Portland Cement ASTM C150	3.15	2.41	*473.6*	*Total Amount of cementitious materials* *_789.3_ lb/yd^3* *c/cm ratio* ***.60***
Blast Furnace Slag	2.99	0.42	*78.9*	
Class C Fly Ash	*2.65*	*1.43*	*236.8*	

Fibers				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of Fibers (mass/volume) (lb/yd^3)*	
Nycon PVA-RF4000	1.3	0.08	*6.8*	*Total Amount of Fibers* *__17.0__ lb/yd^3*
Nycon PVA-RFS400	1.3	0.13	*10.2*	

Aggregates							
Aggregates	*ASTM C330**	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*Volume (ft^3)*
					OD	*SSD*	
Poraver 1-2mm	No	20.0	0.39	0.47	*30.23*	36.43	1.24
Poraver 0.5-1mm	No	25.0	0.47	0.56	*15.11*	18.00	0.52
K1	No	0	0.125	0.125	*39.47*	39.47	5.06
K37	No	0	0.37	0.37	*3.02*	3.02	0.13
Digeronimo Haydite -#8 Sieve	Yes	36.0	1.22	1.66	*181.38*	246.79	2.38

Admixtures					
Admixture	*lb/gal*	*Dosage (fl. Oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
TYLAC 4190	*14.03*	*10.03*	*28.02*	*6.25*	*Total Water from Admixtures, $\sum w_{admx}$* *___8.96___ lb/yd^3*
BASF GLENIUM 3030NS	*9.2*	*6*	*20.27*	*2.71*	

Solids (Latex, Dyes, Powdered Admixtures, and Mineral Fillers)				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
DCI Concrete Pigments- Various Colors	1.19	0.20	14.90	*Total Solids from Admixtures* *___77.60___ lb/yd^3*
K1	0.125	4.55	35.49	
K37	0.37	1.18	27.21	

Water			
	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		*w:* 434.12	*7.20*
Total Free Water from All Aggregates, lb/yd^3		*$\sum w_{free}$:* - 24.33	
Total Water from All Admixtures, lb/yd^3		*$\sum w_{admx}$:* *8.96*	
Batch Water, lb/yd^3		*w_{batch}:* 449.49	

Densities, Air Content, Ratios and Slump						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	789.30	17.00	343.71	77.60	449.49	*$\sum M$: 1677.10*
Absolute Volume of Concrete, V, (ft^3)	4.26	0.21	9.33	5.93	7.20	*$\sum V$: 26.93*
Theoretical Density, T, (=$\sum M / \sum V$)	*62.28 lb/ft^3*		***Air Content [= (T – D)/T x 100%]***			*5.2 %*
Measured Density, D	*59.02 lb/ft^3*		***Slump, Slump flow***			*2.5 in.*
water/cement ratio, w/c:	0.92		***water/cementitious material ratio, w/cm:***			0.55

* *Indicate if aggregate, other than manufactured glass microspheres and/or cenospheres, is compliant with ASTM C330.*

MIXTURE DESIGNATION: FINISHING

CEMENTITIOUS MATERIALS				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Lehigh Type 1 Portland Cement, ASTM C150	3.15	3.86	759.46	Total Amount of cementitious materials __**1012.62**__ lb/yd^3 c/cm ratio ___**0.75**___
Blast Furnace Slag	2.99	1.36	253.15	

FIBERS				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of Fibers (mass/volume) (lb/yd^3)*	
Nycon PVA-RF4000	1.3	0	0	Total Amount of Fibers ___**0**___ lb/yd^3
Nycon PVA-RFS400	1.3	0	0	

AGGREGATES							
Aggregates	*ASTM C330**	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*Volume (ft^3)*
					OD	*SSD*	
Poraver 0.25-0.5 mm	No	30.0	0.59	0.77	13.75	17.88	0.37
Poraver 0.1-0.3 mm	No	35.0	0.90	1.22	38.50	51.98	0.69
K1	No	0	0.125	0.125	37.13	37.13	4.76
Digeronimo Haydite #16 Sieve	Yes	36.0	1.22	1.66	148.51	201.97	1.95

ADMIXTURES					
Admixture	*lb/gal*	*Dosage (fL oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
TYLAC 4190	14.03	13	28.02	10.39	Total Water from Admixtures, $\sum w_{admx}$ ___**14.60**___ lb/yd^3
BASF GLENIUM 3030NS	9.2	8	20.27	4.21	

SOLIDS (LATEX, DYES, POWDERED ADMIXTURES, AND MINERAL FILLERS)				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
DCI Concrete Pigments-various colors	1.19	0.20	14.90	Total Solids from Admixtures __**48.28**__ lb/yd^3
K1	0.125	4.28	33.38	

WATER			
	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		w: 577.19	9.44
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -29.48	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: 14.60	
Batch Water, lb/yd^3		w_{batch}: 589.07	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	1012.62	0	308.96	48.28	589.07	$\sum M$: 1958.93
Absolute Volume of Concrete, V, (ft^3)	5.22	0	7.77	4.48	9.44	$\sum V$: 26.91
Theoretical Density, T, (=$\sum M / \sum V$)	72.80 lb/ft^3		**Air Content [= (T – D)/T x 100%]**			2.66 %
Measured Density, D	70.86 lb/ft^3		**Slump, Slump flow**			11 in.
water/cement ratio, w/c:	0.78		**water/cementitious material ratio, w/cm:**			0.57

* Indicate if aggregate, other than manufactured glass microspheres and/or cenospheres, is compliant with ASTM C330.

Cementitious Materials

$Mass = Given$

$Mass_{Type\ 1\ Portland} = 473.6\ lbs$

$Mass_{Blast\ Furnace\ Slag} = 78.9\ lbs$

$Mass_{Class\ C\ Fly\ Ash} = 236.8\ lbs$

$\boldsymbol{\Sigma Mass_{Cementitious} = 789.3\ lbs}$

$$Volume = \frac{Mass}{SG \cdot 62.4\ lb/ft^3}$$

$$Volume_{Type\ 1\ Portland} = \frac{473.6\ lbs}{3.15 \cdot 62.4\ lbs/ft^3} = 2.41\ ft^3$$

$$Volume_{Blast\ Furnace\ Slag} = \frac{78.9\ lbs}{2.99 \cdot 62.4\ lbs/ft^3} = 0.42\ ft^3$$

$$Volume_{Class\ C\ Fly\ Ash} = \frac{236.8\ lbs}{2.65 \cdot 62.4\ lbs/ft^3} = 1.43\ ft^3$$

$\boldsymbol{\Sigma Volume_{Cementitious} = 4.26\ ft^3}$

Fibers

$Mass = Given$

$Mass_{PVA-RFS4000} = 6.8\ lbs$

$Mass_{PVA-RFS400} = 10.2\ lbs$

$\boldsymbol{\Sigma Mass_{Fibers} = 17.0\ lbs}$

$$Volume = \frac{Mass}{SG \cdot 62.4\ lb/ft^3}$$

$$Volume_{PVA-RFS4000} = \frac{6.8\ lbs}{1.3 \cdot 62.4\ lbs/ft^3} = 0.08\ ft^3$$

$$Volume_{PVA-RFS400} = \frac{10.2\ lbs}{1.3 \cdot 62.4\ lbs/ft^3} = 0.13\ ft^3$$

$\boldsymbol{\Sigma Volume_{Fibers} = 0.21\ ft^3}$

Aggregates

$Mass(W_{OD}) = Given$

$Mass_{Poraver\ 1-2mm} = 30.23\ lbs$

$Mass_{Poraver\ 0.5-1.0mm} = 15.11\ lbs$

$Mass_{K1} = 39.47\ lbs$

$Mass_{K37} = 3.02\ lbs$

$Mass_{Haydite} = 181.38\ lbs$

$\boldsymbol{\Sigma Mass_{Aggregates} = 343.71\ lbs}$

$Mass(W_{SSD}) = Given$

$Mass_{Poraver\ 1-2mm} = 36.43\ lbs$

$Mass_{Poraver\ 0.5-1.0mm} = 18.00\ lbs$

$Mass_{K1} = 39.47\ lbs$

$Mass_{K37} = 3.02\ lbs$

$Mass_{Haydite} = 246.79\ lbs$

$$Volume = \frac{W_{SSD}}{SG_{OD} \cdot 62.4\ lb/ft^3}$$

$$Volume_{Poraver\ 1-2mm} = \frac{36.43\ lbs}{0.39 \cdot 62.4\ lbs/ft^3} = 1.24\ ft^3$$

$$Volume_{Poraver\ 0.5-1.0mm} = \frac{18.00\ lbs}{0.47 \cdot 62.4\ lbs/ft^3} = 0.52\ ft^3$$

$$Volume_{K1} = \frac{39.47\ lbs}{0.125 \cdot 62.4\ lbs/ft^3} = 5.06\ ft^3$$

$$Volume_{K37} = \frac{3.02\ lbs}{0.37 \cdot 62.4\ lbs/ft^3} = 0.13\ ft^3$$

$$Volume_{Haydite} = \frac{246.79\ lbs}{1.22 \cdot 62.4\ lbs/ft^3} = 2.38\ ft^3$$

$$Absorbance\ (Abs) = \frac{W_{SSD} - W_{OD}}{SG_{OD}} \cdot 100\%$$

$$Abs_{Poraver\ 1-2mm} = \frac{36.43\ lbs - 30.23\ lbs}{30.23\ lbs} \cdot 100\% = 20\%$$

$$Abs_{Poraver\ 0.5-1.0mm} = \frac{18.00\ lbs - 15.11\ lbs}{15.11\ lbs} \cdot 100\% = 25\%$$

$$Abs_{K1} = \frac{39.47\ lbs - 39.47\ lbs}{39.47\ lbs} \cdot 100\% = 0\%$$

$$Abs_{K37} = \frac{3.02\ lbs - 3.02\ lbs}{3.02\ lbs} \cdot 100\% = 0\%$$

$$Abs_{Haydite} = \frac{246.79\ lbs - 181.38\ lbs}{181.38\ lbs} \cdot 100\% = 36\%$$

Stock Moisture Content (MC_{stk})

$MC_{Poraver\ 1-2\ mm} = 0.5\ \%$

$MC_{Poraver\ 0.5-1\ mm} = 0.5\ \%$

$MC_{K1} = 0\ \%$

$MC_{K37} = 0\ \%$

$MC_{Haydite} = 27.88\ \%$

Moisture Content

$(MC_{stk}) = MC_{Total} - Abs$

$MC_{Poraver\ 1-2\ mm} = 0.5\ \% - 20\ \% = -19.5\ \%$

$MC_{Poraver\ 0.5-1\ mm} = 0.5\ \% - 25\ \% = -24.5\ \%$

$MC_{K1} = 0\ \% - 0\ \% = 0\ \%$

$MC_{K37} = 0\ \% - 0\ \% = 0\ \%$

$MC_{Haydite} = 27.88\ \% - 36\ \% = -8.12\ \%$

$Free\ Water\ (w_{free}) = W_{OD} * (\frac{MC_{free}}{100\ \%})$

$MC_{Poraver\ 1-2\ mm} = 30.23\ lbs * \left(\frac{-19.5\ \%}{100\ \%}\right) = -5.89\ lbs$

$MC_{Poraver\ 0.5-1\ mm} = 15.11\ lbs * \left(\frac{-24.5\ \%}{100\ \%}\right) = -3.70\ lbs$

$MC_{K1} = 39.47\ lbs * \left(\frac{0\ \%}{100\ \%}\right) = 0\ lbs$

$MC_{K37} = 3.02\ lbs * \left(\frac{0\ \%}{100\ \%}\right) = 0\ lbs$

$MC_{Haydite} = 181.381\ lbs * \left(\frac{-8.12\ \%}{100\ \%}\right) = -14.73\ lbs$

$\sum \boldsymbol{w_{free} = -24.33\ lbs}$

Admixtures

$Dosages = Given$

$Dosages_{Tylac\ 4190} = 10.03\ fl\ oz/cwt$

$Dosages_{BASF\ 3030\ NS} = 6.00\ fl\frac{oz}{cwt}$

$Water\ Content\ \% = (1 - \%\ soilds)$

$WC_{Tylac\ 4190} = 1 - 0.2802 = 0.7198$

$WC_{BASF\ 3030NS} = 1 - 0.2027 = 0.7973$

$$w_{admix} = Dosages * cwt\ of\ cm * WC * \left(\frac{1\ gal}{128\ fl\ oz}\right) * \left(\frac{1\ lb}{gal} admixture\right)$$

$$water_{Tylac\ 4190} = 10.03\ fl\frac{oz}{cwt} * 7.8930\ cwt * 0.7198 * \left(\frac{1\ gal}{128\ fl\ oz}\right) * 14.03\frac{lbs}{gal} = 6.246\ lbs$$

$$water_{BASF\ 3030\ NS} = 6.00\ fl\frac{oz}{cwt} * 7.8930\ cwt * 0.7973 * \left(\frac{1\ gal}{128\ fl\ oz}\right) * 9.2\frac{lbs}{gal} = 2.714\ lbs$$

$\sum \boldsymbol{water_{admixture} = 8.96\ lbs}$

Solids (Pigments and Mineral Fillers)

$Mass = Given$

$Mass_{DCI\ Pigments} = 14.90\ lbs$

$Mass_{K1} = 35.5\ lbs$

$Mass_{K37} = 27.21\ lbs$

$Volume = \frac{Mass}{SG * 62.4\ lbs/ft^3}$

$Volume_{DCI\ Pigments} = \frac{14.90\ lbs}{1.19 * 62.4\ lbs/ft^3} = 0.20\ ft^3$

$Volume_{K1} = \frac{35.5\ lbs}{0.125 * 62.4\ lbs/ft^3} = 4.55\ ft^3$

$Volume_{K37} = \frac{27.21\ lbs}{0.37 * 62.4\ lbs/ft^3} = 1.18\ ft^3$

Water

$$Water = \frac{w}{cm} * cm$$

$$Mass_{water} = 0.55 * 789.3\ lbs = 434.12\ lbs$$

$$Batch\ Water\ (w_{batch}) = w - \left(\sum w_{free} + \sum admix\right)$$

$$w_{batch} = 434.12\ lbs - (-24.33 + 8.96) = 449.49\ lbs$$

$$Volume = \frac{Mass}{SG * 62.4\ lbs/ft^3}$$

$$Volume_{w_{batch}} = \frac{449.49\ lbs}{1 * 62.4\ lbs/ft^3} = 7.20\ ft^3$$

Concrete Analysis

Densities

$$\sum Masses = Mass_{concrete} = 1677.10\ lbs$$

$$\sum Volumes = Volume_{concrete} = 26.93\ ft^3$$

$$Theoretical\ Density\ (T) = \frac{Mass_{concrete}}{Volume_{concrete}} = \frac{1677.10\ lbs}{26.93\ ft^3}$$

$$= 62.28\ pcf$$

$$Measured\ Density\ (D) = 59.02\ pcf$$

Air Content

$$Air\ Content = \frac{T - D}{T} = \frac{62.28\ pcf - 59.02\ pcf}{62.28\ pcf} = 5.2\ \%$$

Important Ratios

$$\frac{Water}{Cement}\ ratio\ \left(\frac{w}{C}\right) = \frac{434.12\ lbs}{473.6\ lbs} = 0.92$$

$$\frac{Water}{Cementitious}\ ratio\ \left(\frac{w}{cm}\right) = \frac{434.12\ lbs}{789.3\ lbs} = 0.55$$

Aggregate Ratio Check

$$\textbf{Aggregate ratio}\ (\%) = \frac{\textbf{Volume}_{aggregate}}{\sum \textbf{Volumes}} = \frac{\mathbf{9.33\ ft^3}}{\mathbf{26.93\ ft^3}}$$

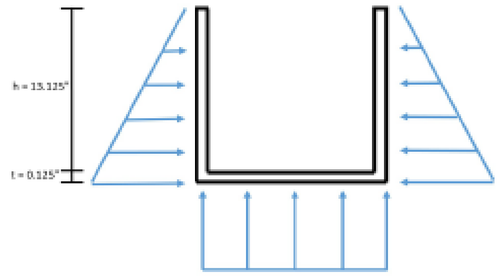
$$= \mathbf{35}\ \% > \mathbf{25}\ \%$$

ASTM C330 Check

$$V_{ASTM\ C330} = \frac{\textbf{Volume}_{haydite}}{\textbf{Volume}_{aggregate}} = \frac{\mathbf{2.38\ ft^3}}{\mathbf{9.33\ ft^3}} = \mathbf{25.51}\ \%$$

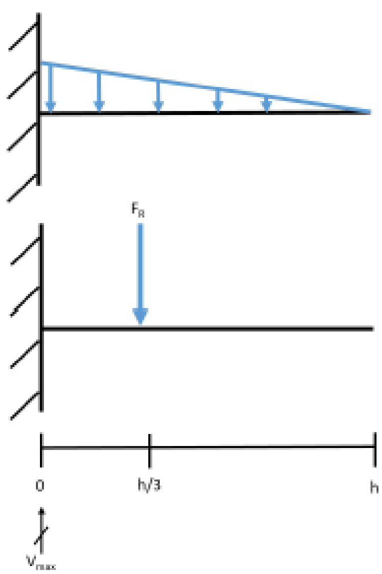
$$> \mathbf{25}\%$$

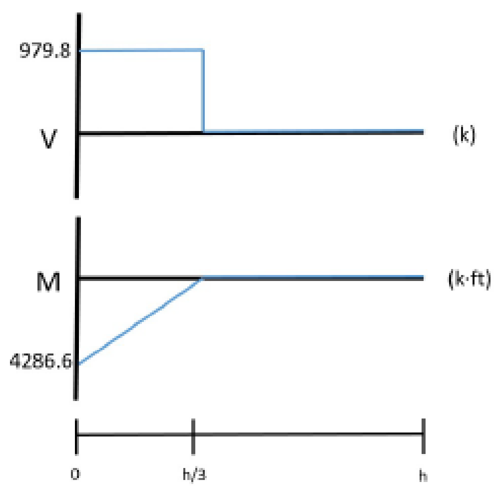
Appendix C – Example Structural Calculations



Shear Stress in Chine:

$\gamma_{water} := 63pcf$	unit weight of brackish water, given
$A := 13.125in \cdot 240in = 3150 \cdot in^2$	area of entire canoe wall
$t := \frac{3}{8}in$	assumed thickness of canoe
$h := 13.5in - t = 13.125 \cdot in$	height of canoe wall
$\phi := 1.3$	dynamic wave action factor
$F_R := \phi \cdot 0.5 \cdot (\gamma_{water}) h \cdot A = 979.8\,lbf$	resultant point load from triangular distributed load
$V_{max} := F_R = 979.8\,lbf$	maximum shear force
$y_{max} := 0in$	distance from neutral axis
$b := 240in$	length of boat
$\tau_{max} := \frac{6V_{max}}{b \cdot t^3} \cdot \left(\frac{t^2}{4} - y_{max}{}^2\right) = 16.3\,psi$	Maximum shear stress in chine





Deflection in Gunwale:

$E := 55.6ksi$ — average modulus of elasticity of the concrete, using stress-strain graphs from split tensile testing

$I := \frac{t \cdot h^3}{12} = 70.7 \cdot in^4$ — second moment of inertia of cross section

$b := \frac{h}{3} = 4.4 \cdot in$ — distance from fixed end

$\Delta_{max} := F_R \cdot \frac{b^2}{6 \cdot I \cdot E} \cdot (3h - b) = 0.0278 \cdot in$ — maximum deflection: at free end (gunwale) *AISC Manual Table 3-23*

Punching Stress:

Assuming maximum shear case is 200 lbs male paddler on one knee):

$P := (200lbf \cdot .75) = 150\,lbf$ 75% of weight

$B1 := 4in \quad B2 := 4in$ Area in Shear: Using a contact area of 4" x 4" for a knee

$d := \frac{3}{8}in$ (assumed thickness of canoe)

$A1 := (B1 + B2)\cdot d = 3\,in^2 \qquad A2 := (B1 + B2 + B2)\cdot d = 4.5\,in^2 \qquad A3 := (B1 + B2)\cdot d\cdot 2 = 6\,in^2$

$Vreq1 := \frac{P}{A1} = 50\,psi \qquad Vreq2 := \frac{P}{A2} = 33.333\,psi \qquad Vreq3 := \frac{P}{A3} = 25\,psi$

$Vreq2\cdot 3 = 100\,psi$

$\lambda := .75$ ACI 318 Table 19.2.4.2

$fc := 12 \qquad \beta := \frac{6}{3} = 2$

$bo1 := (B1 + B2) = 8\,in$ Corner loading, 2 sides

$bo2 := (B1 + B2 + B2) = 12\,in$ Edge loading, 3 sides

$bo3 := (B1 + B1 + B2 + B2) = 16\,in$ Center loading, 4 sides

ACI 318 Table 22.6.5.2

a.) $vca := 4\cdot\lambda\cdot\sqrt{fc} = 10.392$

b.) $vcb := \left(2 + \frac{4}{\beta}\right)\cdot\lambda\cdot\sqrt{fc} = 10.392$

c.) $vc1 := \left(2 + \frac{20\cdot d}{bo1}\right)\cdot\lambda\cdot\sqrt{fc} = 7.632$

$vc2 := \left(2 + \frac{30\cdot d}{bo2}\right)\cdot\lambda\cdot\sqrt{fc} = 7.632$ Controls meets reqiremnts

$vc3 := \left(2 + \frac{40\cdot d}{bo3}\right)\cdot\lambda\cdot\sqrt{fc} = 7.632$

$ts := .00035in \qquad fyt := 682ksi \qquad s := .99in$ 22.6.8.2

$As1 := (B1 + B2)\cdot ts = 2.8 \times 10^{-3}\,in^2$

$As2 := (B1 + B2 + B2)\cdot ts = 4.2 \times 10^{-3}\,in^2$

$As3 := (B1 + B2)\cdot ts\cdot 2 = 5.6 \times 10^{-3}\,in^2$

Applied Loading:

$fc := \left[\frac{(100psi)}{4\cdot\lambda}\right] = 33.333\,psi$

$vs1 := \frac{As1\cdot fyt}{bo1\cdot s} = 241.111\cdot psi \qquad vs2 := \frac{As2\cdot fyt}{bo2\cdot s} = 241.111\cdot psi \qquad vs3 := \frac{As3\cdot fyt}{bo3\cdot s} = 241.111\cdot psi$

The composite is able to withstand a shear of 241.11 psi. The load applied is only 33.33 psi, therefore composite is considered suitable.

Appendix D – Hull Thickness/Reinforcement and Percent Open Area Calculations

HULL THICKNESS CALCULATIONS

Calculations per Section 4.3.1

Annotation

T_G = 0.045 in	Average thickness of first layer of reinforcement, GlasGrid®8511 Mesh, measured in accordance with Section 4.3.1
T_S = 0.050 in	Average thickness of second layer of reinforcement, SpiderLath Mesh, measured in accordance with Section 4.3.1
T_H = 0.375 in	Nominal thickness of the canoe hull

Determine that the reinforcement at any point in the canoe will not exceed 50% of the total hull thickness.

Solution

Within the canoe, a maximum of one layer of GlasGrid®8511 and two layers of SpiderLath were used along the bottom of the canoe.

$$\frac{T_G + 2T_2}{T_H} * 100 = 38.7$$

The two layers of reinforcement make up approximately 38.7% of the hull. This value is less than the maximum value of 50% outlined in section 4.3.1, demonstrating compliance.

GUNNEL CAP THICKNESS CALCULATIONS

Calculations per Section 4.3.1

Annotation

T_S = 0.050 in	Average thickness of the layer of reinforcement, SpiderLath Mesh, measured in accordance with Section 4.3.1
T_W = 0.75 in	Nominal thickness of the gunwale cap

Determine that the reinforcement at any point in the canoe will not exceed 50% of the total hull thickness.

Solution

One layer of SpiderLath Mesh was used throughout the gunnel cap.

$$\frac{T\_s}{T_W} * 100 = 6.67$$

The layer of reinforcement makes up approximately 3.27% of the gunnel cap. This value is less than the maximum value of 50% outlined in section 4.3.1, demonstrating compliance.

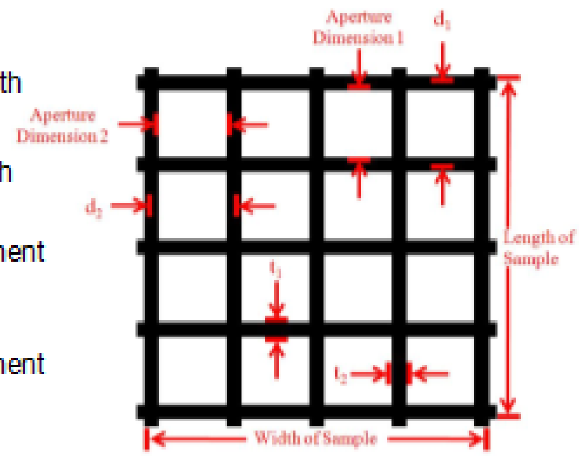
PERCENT OPEN AREA CALCULATIONS

Calculations per Section 4.3.2

Sample: GlasGrid®8511 Mesh

Given

$n_1 = 9$	Number of apertures along length
$n_2 = 5$	Number of apertures along width
$t_1 = 0.262$ in	Average thickness of reinforcement along length
$t_2 = 0.173$ in	Average thickness of reinforcement along width



Sample of Reinforcement

Aperture_Dimension_1 = 0.737 in

Aperture_Dimension_2 = 0.808 in

d_1 = Aperture_Dimension_1 + 2*(t_1/2)	$d_1 = 0.99$ in	Average spacing of reinforcement (center-to-center) along the sample length
d_2 = Aperture_Dimension_2 + 2*(t_2/2)	$d_2 = 0.98$ in	Average spacing of reinforcement (center-to-center) along the sample width

Determine Solution Percent Open Area (POA) for the GlasGrid®8511 Mesh

$Length_{Sample} = n_1 * d_1$	$Length_{Sample} = 8.98$ in
$Width_{Sample} = n_2 * d_2$	$Width_{Sample} = 4.91$ in
$Area_{Open} = n_1 * n_2$ *Aperture_Dimension_1*Aperture_Dimension_2	$Area_{Open} = 680$ in^2
$Area_{Total} = Length_{Sample} * Width_{Sample}$	$Area_{Total} = 1120$ in^2
$POA = (Area_{Open}/Area_{Total})*100$	POA = 60.7%

The POA is greater than the 40% minimum required, demonstrating compliance.

DRIFTWOOD

PERCENT OPEN AREA CALCULATIONS

Calculations per Section 4.3.2

Sample: SpiderLath Mesh

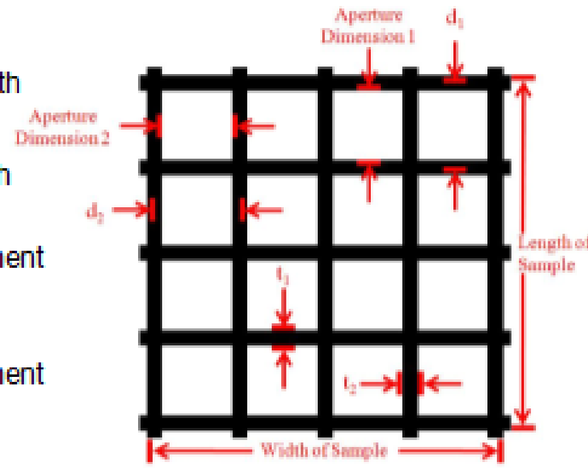
Given

$n_1 = 34$ — Number of apertures along length

$n_2 = 35$ — Number of apertures along width

$t_1 = 0.103$ in — Average thickness of reinforcement along length

$t_2 = 0.051$ in — Average thickness of reinforcement along width



Sample of Reinforcement

Aperture_Dimension_1 = 0.312 in

Aperture_Dimension_2 = 0.288 in

d_1 = Aperture_Dimension_1 + 2*(t_1/2) $d_1 = 0.42$ in — Average spacing of reinforcement (center-to-center) along the sample length

d_2 = Aperture_Dimension_2 + 2*(t_2/2) $d_2 = 0.34$ in — Average spacing of reinforcement (center-to-center) along the sample width

Determine Solution Percent Open Area (POA) for the GlasGrid®8511 Mesh

$Length_{Sample} = n_1 * d_1$ $Length_{Sample} = 14.09$ in

$Width_{Sample} = n_2 * d_2$ $Width_{Sample} = 11.85$ in

$Area_{Open} = n_1 * n_2$ *Aperture_Dimension_1*Aperture_Dimension_2 $Area_{Open} = 106.76\ in^2$

$Area_{Total} = Length_{Sample} * Width_{Sample}$ $Area_{Total} = 167.05\ in^2$

$POA = (Area_{Open}/Area_{Total})*100$ POA = 63.9%

The POA is greater than the 40% minimum required, demonstrating compliance.